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Conifer and Vegetation Responses to Pre-planting Applications of Glyphosate and Hexazinone on a Boreal Backlog Site, Sx Trial 82502G-2

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R. Kabzems and G.J. Harper

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SUMMARY

We examined conifer and vegetation responses to pre-planting applications of glyphosate and hexazinone 30 years after establishment on a boreal site with a history of logging and wildfire. The chemical treatments were effective in assisting the establishment of white spruce as a dominant tree in the mixed-species stands that have developed. Only 100 stems per hectare of spruce were present in the aspen-dominated stand where no spruce planting or other treatment had been conducted post-wildfire. Broadleaf trees were 19%, 24%, and 99% of the stand basal area in the glyphosate treated, hexazinone treated, and untreated areas, respectively. The untreated area was following a successional development trajectory typical of shade-intolerant tree species. The treatments had a strong influence on composition of the vegetation community 30 years after establishment. The variation of spruce, broadleaf trees, willow, and alder in both presence and stand structure reflected the site history. At this successional stage, the chemically treated areas had a greater diversity of native understorey plant species due to the variety of habitats created by disturbance rather than by the invasion of non-native species. Growth model projections indicated that total stand volumes 60 years post-disturbance were greater in the conifer-dominated chemically treated areas. After 30 years, the combination of treatments applied in this research trial created diverse plant communities, which over time are becoming more similar to those that develop after wildfire in similar boreal ecosystems.

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1 INTRODUCTION

During the 1980s in Canada, the concern for regeneration of conifer forests resulted in Forest Resource Development Agreements that were cost shared equally between the federal and provincial governments. These agreements funded research and operational activities with the goal of re-establishing conifers in areas in which they had not regenerated after harvest or wildfire. Similar to many areas in the southern boreal forest, spruce regeneration was very poor after white spruce (*Picea glauca* (Moench) Voss) was selectively harvested for saw timber in the Peace River area of British Columbia from 1912 until the late 1960s. As part of the national forest renewal program, Les Herring, a research silviculturist with the British Columbia Ministry of Forests, established a series of vegetation management trials near Dawson Creek in the 1980s to provide information that would guide conifer establishment on areas that had previously supported white spruce and lodgepole pine (*Pinus contorta* var. *latifolia* [Douglas ex Louden Englm ex S. Watson]) forests. The intent of SX82502G-2, established in 1982, was to examine the effectiveness of treating a juvenile broadleaf-dominated stand with herbicides (glyphosate, hexazinone) and/or mechanical shearing prior to conifer planting.

Historically in British Columbia, broadleaf tree species have been undervalued and considered only as detriments to conifer growth rather than as positive economic and ecological contributors (Harper and Roach 2014). With the increased economic use of broadleaf species, particularly trembling aspen (*Populus tremuloides* Michx.), forest managers are actively pursuing approaches to managing mixed-species forests, where both conifers and broadleaf components provide quality wood fibre for a variety of forest products. The use of pre-harvest applications of glyphosate to control the composition of regeneration in mixedwood stands, as in SX8250G-2, is being examined again in Ontario (Man et al. 2010, Man et al. 2011).

Trial SX82502G-2 now provides the opportunity to improve boreal forest management practices by considering a wider range of forest ecosystem properties and values. In particular, this trial is a 30-year old experimental study of the pre-harvest application of chemicals to create a conifer–broadleaf mix. This report summarizes data collected in 2012, 30 years after establishment of the experiment. Information provided here will support forest management objectives regarding stand development, vegetation community response, plant species diversity, and stand growth and yield.

2 OBJECTIVES

The questions addressed by the 2012 remeasurement were:

1. How did the treatments influence white spruce growth, vigour, and condition?
2. How much spruce natural regeneration was present in control plots 41 years after disturbance?
3. How did the treatments influence broadleaf stand development?
4. How did the treatments influence vegetation community composition?
5. How did the treatments affect plant species diversity?
6. How did the treatments influence future timber yields?

3 METHODS

3.1 Site Description

The trial was established at kilometre 3 of the Stewart Lake Road (55°50′N, 121°08′W; elevation 80 m), approximately 50 km west of Dawson Creek, B.C. The site is within the Moist Warm variant of the Boreal White and Black Spruce biogeoclimatic zone (DeLong et al. 2011). Mean annual temperature is 1.9°C, mean annual precipitation is 515 mm, mean growing-season precipitation is 315 mm, mean frost-free period is 94 days, and total number of frost-free days is 157 (based on 1971–2000 climate normals from ClimateBC [Wang et al. 2006]). Soils are dominantly Brunisolic Gray Luvisols developed on moraines with loamy surface textures and low coarse fragment content (Lord and Green 1986). The trial plots were similar in site characteristics and were classified as having fresh to moist soil moisture regimes and medium to rich soil nutrient regimes (DeLong et al. 2011).

A sawmill was located at Stewart Lake, and the surrounding area was actively logged until 1969. No information on logging history is available for the trial site. Old, cut conifer stumps were observed in the area during fieldwork. In logged areas associated with the Stewart Lake sawmill, white spruce seed trees and seed tree reserves were used for spruce regeneration. Major wildfires swept through the area in 1969 and 1971. Aspen, balsam poplar (*Populus balsamifera* L.), willow (*Salix* spp.), and alder (*Alnus* spp.) dominated regeneration after the wildfire events, consistent with other locations in the boreal forest (Taylor et al. 2013).

3.2 Trial Design

The trial was established in a juvenile (11 years post-wildfire) broadleaf-dominated stand. Two complete blocks of two treatments (hexazinone plus shearing, glyphosate plus shearing) and a control (no shearing or chemical application; i.e., "reserve") were established in each block (Figure 1). In May 1983, hexazinone was applied with "Velpar gridballs" at a rate of 4 kg/ha using a helicopter and aerial bucket. In June 1983, glyphosate was aerially applied at a rate of 3 kg/ha using a spray system. In December 1983, when soils were frozen, the existing vegetation on the chemically treated plots was cleared using crawler tractors with dozer blades. Due to the frozen soil conditions, the blades sheared off vegetation and woody debris without "excessive" soil disturbance. In May 1984, plots were operationally planted with container-grown (PSB 415) white spruce seedlings. In 1993, as part of an operational brushing of spruce plantations in the Stewart Lake area, the broadleaf trees present on the chemically treated sites were spaced to a target density of 2000 stems per hectare (sph). In 2011, the reserve in Block 1 was lost due to clearing of a right-of-way.

In June 2012, sample plots were randomly located within treatment plots, and plot centres were marked. Prior assessments of the study could not be used because very few plot and sample tree markers from the establishment of the experiment were present in 2012. The numbers of sample plots are given in Table 1. To avoid edge effects, a 5 m wide area along the treatment plot boundaries was not sampled. In July 2012, 3.99 m radius (0.005-ha) plots were established at the randomly located plot centres in order to assess vegetation community composition. In September 2012, trees and tall shrubs were assessed within a 5.64-m radius of the same randomly located plot centres. All tree species (aspen, balsam poplar, paper birch, white spruce, lodgepole

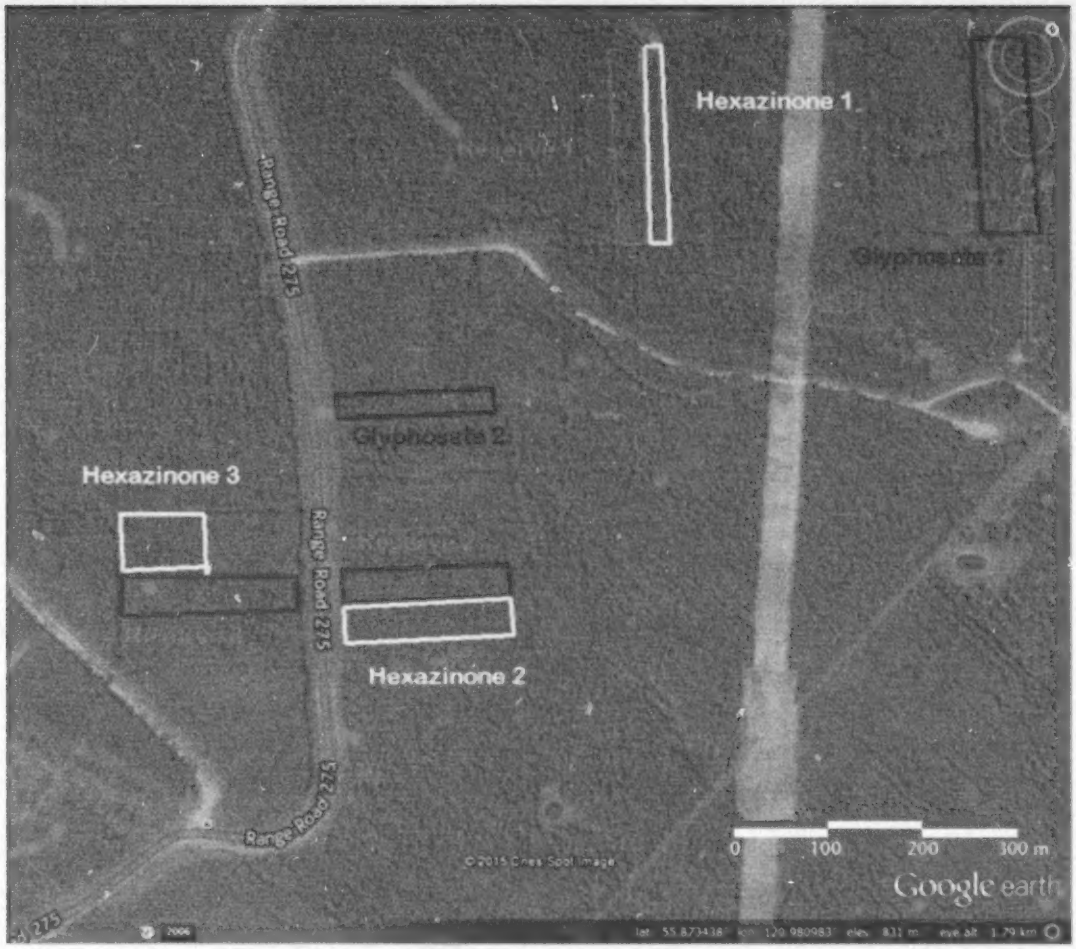

FIGURE 1 *Aerial view of trial Sx82502G-2 in 2014 with glyphosate, hexazinone, and reserve treatment areas outlined.*

TABLE 1 *Treatments, existing replicate plots, and number of samples for remeasurement of Sx82502G-2*

Treatment	Existing replicate plots	Number of samples
Hexazinone	3	18
Glyphosate	2	10
Reserve	3	12

pine) and tall shrubs (willow, alder), both alive and dead, within the plot, were measured for diameter at 1.3 m (diameter at breast height [dbh]). Total height of the three largest individuals of each species within the sample plot was measured. Tree and shrub species, both alive and dead, less than 1.3 m in height were tallied. Each tree and tall shrub was also evaluated for pests and damaging agents using forest health damage agent and condition codes (Appendix 1a). In July of 2012, percent cover and height were recorded for

each vascular plant species; only percent cover was recorded for mosses (Appendix 1b).

Site index for all tree species was determined using Site Tools software (BC MOFR 2004). The Mixedwood Growth Model (MGM) (version 2012, Bokalo et al. 2013) was used to make yield projections.

Statistical analyses were conducted using analysis of variance (ANOVA) and planned comparisons. Tree data were analyzed using SAS (SAS Institute 2010); vegetation data were analyzed using SYSTAT 11 (SPSS Inc. 2004).

The original trial design did not allow for any replication, and therefore provided limited statistical power. The original design may be considered an Incomplete Block Design (IBD) with three treatments and two blocks. The statistical analysis based on the IBD using Proc Mixed and Proc GLM (SAS) resulted in little evidence of consequence. In order to provide more power to the statistical analysis, the 40 sample plots were used as replication within a simple Proc GLM pseudo-replication design with no blocks and interaction terms. The resulting ANOVA (Tables 2 and 3) had treatments and plots only: 18 plots hexazinone, 10 plots glyphosate, and 12 plots reserve. For the ANOVA, tree-level variables were summarized to the plot level. Data are presented as treatment means based on the plot-level summaries.

To test for treatment differences (pseudoreplication), the randomly located plots were considered as experimental units. As such, testing of means represents a comparison of plots and is limited in its reference to similar herbicide and site preparation treatments. The concern with pseudoreplication is that the effect produced by the treatment cannot be statistically differentiated from the effect of being in a particular plot. However, due to the relative homogeneity of the study area (topography, slope, aspect, original vegetation), plot-to-plot variability is minimized, which provides greater confidence in the general interpretation of the results.

Results from a single study are applicable only to that site. Treatment response may be affected directly or in interaction with a number of factors other than the treatments (Harper et al. 1997). Variation in stock quality, stock development, climate, soil nutrient and moisture regime, vegetation competition, or soil type may influence conifer and vegetation response to

TABLE 2 *Analysis of Variance of treatment data*

Source of variation	Factor type	Level	Degrees of freedom (df)	Expected *F* test (df)
Treatments	Fixed	3	2	Mean squares treatments Mean squares sample plots
Sample plots S(T) (error term)	Random	40	39	
Total			39	

TABLE 3 *Planned comparisons of treatment data*

	Coefficient		
Contrast	**a**	**b**	**c**
Reserve vs. glyphosate	1	-1	0
Reserve vs. hexazinone	1	0	-1
Glyphosate vs. hexazinone	0	1	-1

treatments (Harper et al. 1997). Herbicide efficacy is affected by such factors as phenology of target species, application rate, formulation, application method, and weather (Harper et al. 1997).

ANOVA and planned comparisons were used to determine whether the treatments had a significant effect on the diameter and height of the planted spruce, and whether there were significant treatment differences in the number and species of broadleaf species present. To allow that these comparisons could be made approximately 28 years after seedlings were planted, it was assumed that the spruce seedlings within each treatment area were of similar size and condition when planted. Vegetation data were also analyzed for treatment differences, and it was recognized that the control areas had broadleaf regeneration that was 11 years older than the broadleaf present on the treatment plots.

Question: How did the treatments influence white spruce growth, vigour, and condition?

The planted white spruce in the glyphosate and hexazinone treatments had good stocking, averaging 1660 and 1639 sph, respectively (Table 4). White spruce accounted for more than 50% of the stand basal area 28 years after the glyphosate and hexazinone treatments (Table 4). White spruce and lodgepole pine are dominants in the mixed-species stands that have developed after these treatments (Figure 2).

TABLE 4 *Mean tree density (stems per hectare [sph]) and basal area (m^2/ha) of both live and dead stems in each treatment. Densities are divided into two height groups: trees >1.3 m tall, and trees <1.3 m.*

Species[1]	Treatment	Total density (sph) alive	Total density (sph) dead	>1.3 m density (sph) alive	>1.3 m density (sph) dead	<1.3 m density (sph) alive	<1.3 m density (sph) dead	Basal area (m^2/ha) alive	Basal area (m^2/ha) dead
Acb	Glyphosate	729	857 b[2]	700	286 b	29	571 ab	3.6	0.210 b
	Reserve	867	800 b	844	7889 ab	22	11 b	6.8	1.743 a
	Hexazinone	7545	5380 a	745	2590 a	9	2790 a	1.1	0.381 b
At	Glyphosate	480 b	783 b	460 b	383 b	20	400 ab	1.1 b	0.075 b
	Reserve	3550 a	2292 a	3533 a	2275 ab	17	17 b	30.0 a	3.248 a
	Hexazinone	586 b	3634 b	586 b	2723 b	0	91 b	5.4 b	0.901 b
D	Glyphosate	1520	1180 a	860	640	660	540	1.7	0.857
	Reserve	100	1000 a	100	1000	0	0	0.1	2.452
	Hexazinone	3430	4023 a	3230	3339	200	685	3.8	1.542
Ep	Glyphosate	650	200	475	0 b	175	200	0.8	–
	Hexazinone	100	100	100	100 a	0	0	0.1	0.049
Pl	Glyphosate	450	100	375	0	75	100	9.4	–
	Hexazinone	500	100	500	100	0	0	6.3	0.442
Sw	Glyphosate	1660 a	100	1570 a	100	90	0	13.0 ab	0.006
	Reserve	100 b	–	33 b	–	67	–	0.1 b	–
	Hexazinone	1639 a	100	1594 a	100	44	0	20.6 a	0.003
W	Glyphosate	4380 a	6470	1900	1760	2480 a	4710	4.6	1.747
	Reserve	2289 ab	4013	1122	2563	1167 ab	1450	3.0	1.838
	Hexazinone	906 b	5212	718	1812	188 b	3400	0.5	0.327
Grand total	Glyphosate	7990 a	8190	4960	2520	3030 a	5670 a	24.2 b	2.176 b
	Reserve	5950 ab	5650	5025	4658	925 b	992 b	36.9 a	5.831 a
	Hexazinone	5206 b	11,056	4867	5744	339 b	5311 a	27.3 b	2.059 b

1 Acb = balsam poplar; At = trembling aspen; D = alder spp.; Ep = paper birch; Pl = lodgepole pine; Sw = white spruce; W = willow spp.
2 Means followed by different letters signify statistical difference at $p \leq 0.05$ (Tukey HSD test).

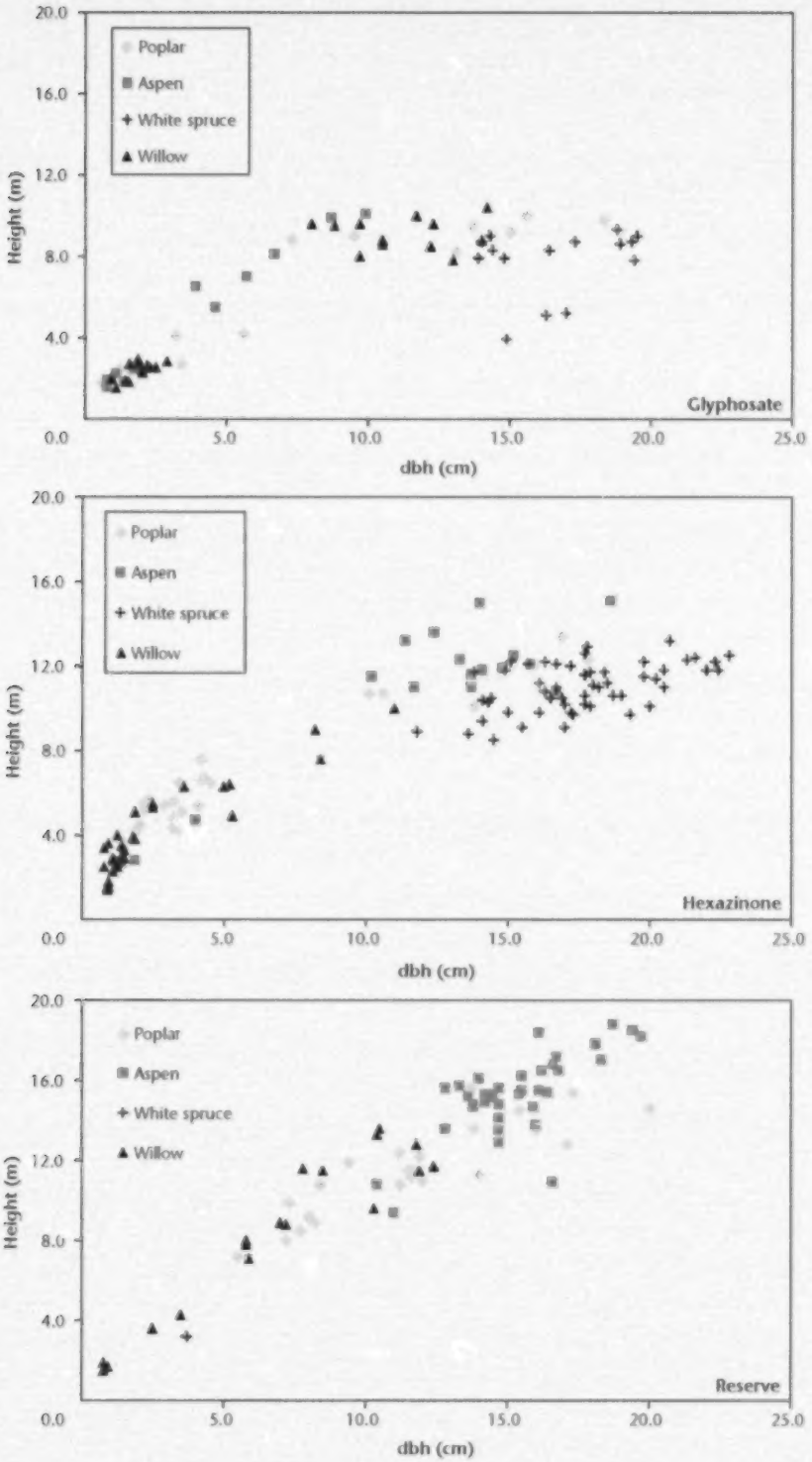

FIGURE 2 *Height distribution by tree and tall shrub species in the treatment areas.*

Damaging agents affected 6.6% of white spruce in the hexazinone treatment and 2.6% in the glyphosate treatment. The cause of the damage in the hexazinone treatment could not be readily determined for most damaged trees. Bark shredding by black bears was the second most common type of damage observed. Competition with adjacent vegetation was the most common agent that negatively affected spruce in the glyphosate treatment.

The average size of white spruce was larger in the hexazinone treatment than in the glyphosate treatment (Figure 3). This difference may have been due to the greater density (Figure 4) and basal area of live willow (Figure 5) in the

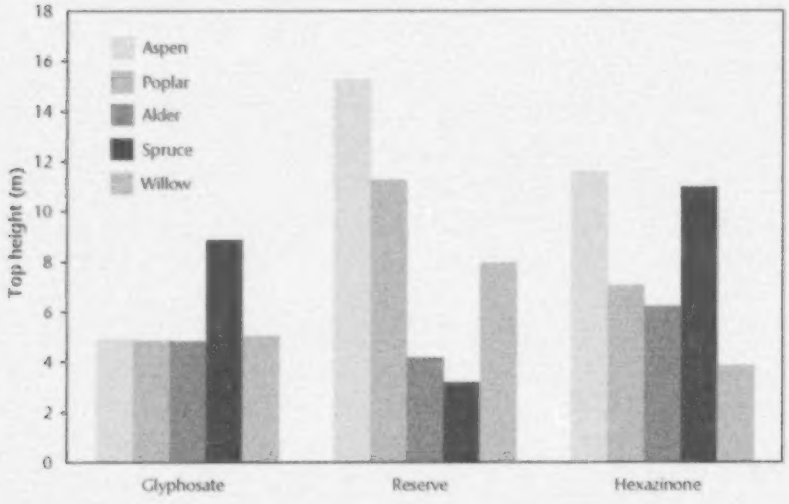

FIGURE 3 *Mean top height for tree and tall shrub species (height of three largest per plot) in the treatments.*

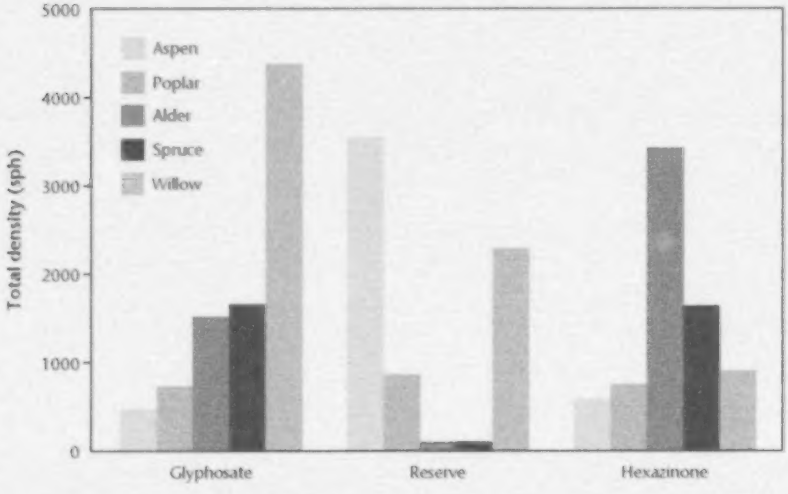

FIGURE 4 *Total density (stems per hectare [sph]) of all live stems by treatment and species.*

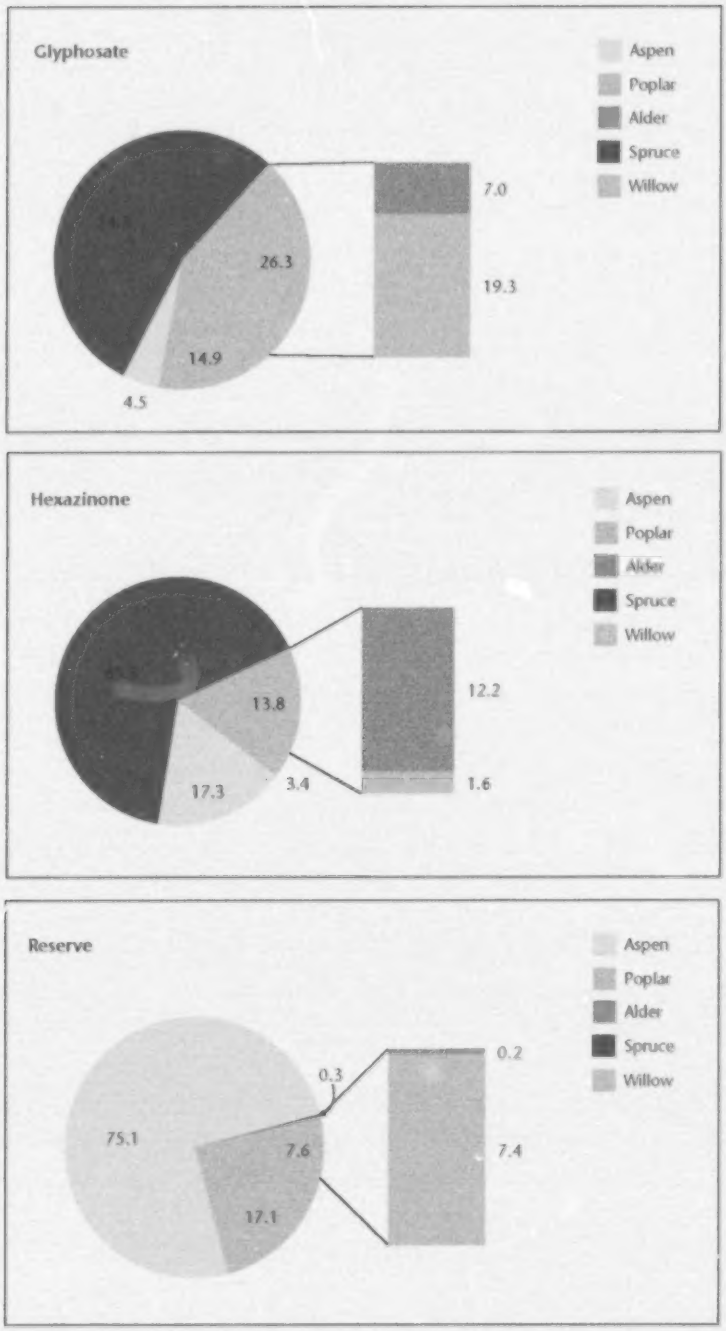

FIGURE 5 *Tree and tall shrub basal area (%) by species in each treatment.*

glyphosate treatment compared with the hexazinone treatment, which would have created a more competitive environment for the young spruce. The alder species were shorter than the willow species, and may have been less of a competitor for light, and may have improved soil nitrogen availability by aiding nitrogen fixation.

The glyphosate and hexazinone treatments were effective in assisting the establishment of white spruce. Unpublished reports and file notes indicate that, at this trial, the chemical treatments reduced broadleaf density in the short term. It is important to note that the diameter and height growth of spruce measured in 2012 were also influenced by operational thinning of the broadleaf component on these sites in 1993. In Ontario, pre-harvest glyphosate application achieved the goal of reducing the density and growth rate of aspen without having negative effects on the measures of aspen quality examined. Seven years after treatment, the aspen regeneration of 6580 sph, while significantly lower than the clearcut control of 19 184 sph, would still represent significant competition for conifers (Man et al. 2011).

Question: How much spruce natural regeneration was present in the control plots 41 years after disturbance?

The assessment in 2012 was unable to differentiate between natural or artificial regeneration of conifers. All white spruce in the reserve treatment were considered to be natural regeneration because no artificial regeneration was described in the experimental record. Total density of white spruce in the reserve treatment was 100 sph (Table 4). The density of white spruce less than 1.3 m tall, which may have included natural regeneration, was less than 6% of the total density of white spruce in the glyphosate and hexazinone treatments but was 67% of the total density of white spruce in the reserve treatment (Table 4).

Pre-disturbance species composition and fire severity are the two most important factors that determine regeneration after wildfire (Hart et al. 2010). White spruce seed sources would have been extremely limited in the study area after the combination of conifer harvesting and short-interval wildfires. Fire intervals less than 20 years combined with removal of white spruce seed sources by logging magnify the shift toward aspen-dominated forest after disturbance in boreal mixedwoods (Weir and Johnson 1998).

White spruce seed production usually begins at 30 years of age or older (Nienstaedt and Zasada 1990). Regeneration of white spruce in the reserve treatments via seed rain from nearby planted white spruce is likely to occur, given the short distances between treatments. There will likely be a further delay in establishment because the timing and quantity of spruce natural regeneration will depend on the random effects of a suitable seedbed and favourable microclimate combining with the amount and frequency of viable seed production from nearby white spruce (Coates et al. 1994; Peterson and Peterson 1994).

Question: How did the treatments influence broadleaf stand development?

Together, aspen and balsam poplar comprised 19% of stand basal area in the glyphosate treatment and 24% in the hexazinone treatment but more than 99% of the reserve treatment (Table 4). Aspen and balsam poplar were a component of the dominants and co-dominants in the glyphosate and hexazinone treatments (Figure 2). Aspen and balsam poplar were also present as

individuals less than 5 m in height in both the chemical treatments. In 1984, one growing season after clearing, broadleaf tree density was 1 200 sph on the hexazinone and 2200 sph on the glyphosate pre-treated plots, compared with 32 600 sph on the controls (unpublished file note). The operational stand tending report from 1994 described the area as having more than 13 000 sph of broadleaf trees prior to treatment and 2760 sph post-treatment (unpublished file note).

The reserve treatment has followed a classic successional trajectory for shade-intolerant species after a stand-replacing disturbance (Oliver and Larson 1996). For most shade-intolerant boreal tree species, post-fire regeneration densities are positively related to the pre-fire stand basal area (Greene and Johnson 1999; Chen et al. 2009), which indicates the importance of regeneration by seed and vegetative buds that are available for post-fire natural regeneration (Taylor et al. 2013). At stand initiation immediately after the Stewart Lake wildfires, aspen, balsam poplar, and willow would have regenerated from bud banks. Balsam poplar and willow may have also recruited from seed and root collar sprouts (Haeussler and Coates 1986; Peterson et al. 1996). All three of these species had the ability to rapidly occupy the available growing space. As these species grew in height and competed for light, density would have decreased dramatically during the stem exclusion phase (Chen and Popadiouk 2002). Forty-one years after disturbance, aspen dominated the stand structure, with 15 m tall stems forming most of the upper canopy. Balsam poplar occurred both as co-dominants and in lower canopy positions, ranging from 8 to 14 m in height. Willow occupied a wide range of positions in the reserve treatment canopy, from 2 to 12 m in height.

The glyphosate treatment was dominated by white spruce and lodgepole pine, 7.5–11.0 m tall, where broadleaf species were a minor component. Willow were present in two groupings: as co-dominant stems 7.5–10.0 m tall, and as much shorter 1–3 m tall stems. Aspen and balsam poplar comprised a minor proportion of stems, and were present in two general height classes: as co-dominants over 8 m tall, and as relatively short individuals less than 3 m tall. The structure and composition of the hexazinone treatment was similar to that of the glyphosate treatment.

In the glyphosate and hexazinone treatments, a component of very low-height willow and balsam poplar was present. These short individuals may have been due to (1) less vigorous individuals that regenerated from seed on mineral soil seedbeds created by the shearing treatments, (2) the manual brushing in 1993, which would have temporarily reduced heights but allowed stump sprout regeneration, and (3) repeated browsing by ungulates.

Alder stems 4–7 m tall comprised 12.2% of the basal area of the plant community in the hexazinone treatment, 7.0% in the glyphosate treatment, and 0.2 % in the reserve treatment (Figure 5).

Heights of aspen in the glyphosate treatment (4.9 m) were significantly shorter than those in the hexazinone treatment (11.6 m) (Tables 5 and 6). Site index for aspen, as calculated in Site Tools, was 19.1 in both the hexazinone and reserve treatments compared with 9.3 in the glyphosate treatment. The pre-disturbance aerial spraying of glyphosate in this experiment appears to have had effects on aspen height growth that are still significant 30 years after application. A pre-harvest glyphosate application in Ontario had a significant effect only on aspen height increment in the first 3 years of sucker growth after harvest (Man et al. 2011).

TABLE 5 *Mean height and diameter at breast height (dbh) by species and treatment, both alive and dead*

Species[1]	Treatment	Height (m) alive	Height (m) dead	dbh (cm) alive	dbh (cm) dead
Acb	Glyphosate	4.857 b[2]	4.515	4.537	2.406 b
	Reserve	11.293 a	10.100	8.734	5.329 a
	Hexazinone	7.074 b	4.108	5.355	1.213 b
At	Glyphosate	4.929 b	1.757 b	3.056 b	1.085 b
	Reserve	15.292 a	–	9.746 a	3.981 a
	Hexazinone	11.610 a	5.642 a	10.96 a	4.840 a
D	Glyphosate	4.842	5.100	3.562	2.818
	Reserve	4.200	5.833	3.100	5.040
	Hexazinone	6.223	4.433	3.602	2.481
Ep	Glyphosate	4.122	–	2.687	–
	Hexazinone	7.500	2.600	3.000	2.500
Pl	Glyphosate	10.289	–	16.567	–
	Hexazinone	10.317	5.100	12.898	7.500
Sw	Glyphosate	8.877 a	–	9.214 ab	0.900
	Reserve	3.200 b	–	3.700 b	–
	Hexazinone	10.985 a	–	12.276 a	0.600
W	Glyphosate	5.052 ab	2.025 b	3.261 ab	2.174 a
	Reserve	7.969 a	6.050 a	4.616 a	2.819 a
	Hexazinone	3.856 b	2.577 b	1.769 b	0.915 b

1 Acb = balsam poplar; At = trembling aspen; D = alder spp.; Ep = paper birch; Pl = lodgepole pine; Sw = white spruce; W = willow spp.

2 Means followed by different letters signify statistical difference at $p < 0.05$ (Tukey HSD test).

TABLE 6 *ANOVA p-value results (Proc GLM) for alive stems by species for density, height, diameter at breast height (dbh), and basal area*

Species[1]	Total density	Density > 1.3 m	Density < 1.3 m	Height	dbh	Basal area (m^2/ha)	*n* (plots) (dbh)	*n* (plots) (density)	*n* (plots) (basal area)
Acb	0.9618	0.9626	0.6958	0.0003	0.0635	0.0674	27	27	27
At	<0.0001	<0.0001	0.6937	<0.0001	0.0011	0.0001	23	24	23
D	0.1351	0.0466	0.3628	0.1110	0.9010	0.1877	15	16	15
Ep	0.3977	0.3970	0.5311	0.4339	0.8116	0.5627	4	5	4
Pl	0.8619	0.6897	0.3559	0.9677	0.2243	0.4593	7	8	7
Sw	0.0019	0.0015	0.3226	<0.0001	0.0022	0.0017	29	31	29
W	0.0138	0.1738	0.0153	0.0254	0.0420	0.0661	33 (ht-31)	36	33
Grand total	0.0534	0.9651	0.0057	–	–	0.0013	–	40	40

1 Acb = balsam poplar; At = trembling aspen; D = alder spp.; Ep = paper birch; Pl = lodgepole pine; Sw = white spruce; W = willow spp.

In the reserve treatment, 42.8% of all standing aspen stems (alive and dead) were evaluated as being healthy. Tree mortality is high during the stem exclusion phase in areas with high initial stem densities (Hart et al. 2010), which continues up to 50–80 years after disturbance. Tree competition, unknown causes, and hypoxylon canker were the three most common damaging agents on dead aspen, followed by moose damage and snow- or ice press. On live aspen, the most common damaging agents were moose browsing and snow- or ice press. Most aspen that were alive in the glyphosate and hexazinone treatments were healthy in 2012. Aspen that had been girdled during operational brushing in 1993 and were still standing comprised 18% ($n = 71$) of the standing live and dead stems. The operational girdling comprised the largest single category of damage to aspen.

Question: How did the treatments influence vegetation community composition?

Competitive species such as trembling aspen can sustain their dominance on fertile and fresh boreal sites after disturbance (Hart et al. 2010). The leaf area of aspen increases with increasing basal area in stands up to about 40 years of age (Comeau 2001). Less than 30% of full sunlight would be present under the aspen-dominated canopy of 37 m^2/ha in the reserve treatment (Comeau 2001). The leaf area of understorey shrubs would be at a minimum when overstorey aspen leaf area is at a maximum at this stage of succession (Comeau et al. 2004). For a shade-tolerant species such as white spruce, survival of planted seedlings can still be more than 90% under aspen with basal areas up to 51 m^2/ha (Comeau et al. 2004).

The glyphosate treatment had a higher total stem density than the hexazinone treatment due to the number of willow stems (Table 4). The results of this trial are similar to those of Harper et al. (1997), where, 12 years post-application, the glyphosate treatment had greater willow cover and hexazinone had greater alder cover. In the hexazinone treatment, several factors combined to favour alder regeneration. Effective chemical control of willow created both physical space and a less competitive environment for alder establishment and initial growth. The shearing treatment created suitable seedbeds, and alder from adjacent areas provided the seed source. Seed-origin alder were less of a competitor for the planted white spruce in the chemical treatments.

The high numbers of dead willow stems were a reflection of natural succession (Table 4), where shorter stems of the shade-intolerant willows die out due to decreased light availability in aspen stands during the stem exclusion phase (Oliver and Larsen 1996; Redburn and Strong 2008).

Spruce basal area, height, and dbh were greater (although not significantly) in the hexazinone than in the glyphosate treatment (Tables 4, 5, and 6). The differences 28 years after treatment reflected a combination of the efficacy of the initial treatment in 1983, the effects of reducing broadleaf stem density to 2000 sph in 1993, and the characteristics of the plant community that has developed on each treatment type. The difference in spruce growth between the two treatments was likely due to the competitive environment created by the density of willow combined with balsam poplar, rather than to aspen density. The density of live willow was significantly greater in the glyphosate treatment than in the hexazinone treatment ($p = 0.0138$), and the basal area of both live willow (4.6 versus 0.52 m^2, not significant) and dead willow (1.7 versus 0.3 m^2, not significant) was greater in the glyphosate treatment (Table 4). Balsam poplar basal area was greater in the glyphosate treatment than in the hexazinone treatment (3.6 versus 1.1 m^2, not significant), which indicated that there was a more competitive environment for the spruce, and the significantly greater density of dead balsam poplar stems in the hexazinone treatment ($p = 0.0103$) indicated a greater reduction in interspecific plant competition in that treatment.

Question: How did the treatments affect plant species diversity?

Species richness (number of species) was used to compare plant species diversity in the treatment plots. The number of species found within each stratum (tree, shrub, herb, and moss layer) was also compared.

The glyphosate treatment had 70 species in total (Table 7). It had the greatest number of tree species (5), shrub species (15), and herb layer species (45). The hexazinone treatment had the greatest number of moss species (Table 7). The reserve treatment had the lowest number of total species (Table 7). Similar to Bell and Newmaster (2002), the silviculture treatments did not create a monoculture of tree species. The numbers of tree and shrub species were the same on this site 30 years post-treatment as on a nearby 12-year-old backlog rehabilitation site (Harper et al. 1997). The total numbers of herb layer species and mosses were greater on this site than on the nearby 12-year-old backlog site (Harper et al. 1997).

TABLE 7a *Mean species richness*

	Mean number of species per replicate plot				
Treatment	**Trees**	**Shrubs**	**Herbs**	**Mosses**	**Total**
Glyphosate	3a[1]	7	17a	2a	29a
Hexazinone	2b	7	14b	1a	24b
Reserve	2b	6	17a	0b	25b
p value	<0.001	0.865	0.003	0.004	0.002

1 Means followed by different letters signify statistical difference at $p<0.05$.

TABLE 7b *Total species richness*

	Total number of species within treatments				
Treatment	**Trees**	**Shrubs**	**Herbs**	**Mosses**	**Total**
Glyphosate	5	15	45	5	70
Hexazinone	4	13	41	6	64
Reserve	3	13	39	0	55
Site total	5	15	55	6	81

The relatively low number of species in the aspen-dominated reserve treatment is in contrast to the expected plant diversity in aspen and conifer forest types (Macdonald and Fenniak 2007). A literature review indicated that biodiversity, plant cover, and productivity are higher in understorey plant communities of aspen stands compared with conifer stands (St. Clair et al. 2013). High understorey plant biodiversity in boreal aspen stands has been attributed to greater light availability and soil nutrient and water availability (St. Clair et al. 2013). In northwestern Alberta, 69 understorey species were identified in a pre-harvest aspen forest; 87 understorey species were identified post-harvest (Bradbury 2004). Two years post harvest, the appearance of early seral plant species was additive to the typical forest species that survived harvesting.

Total vegetation cover of all strata combined was not significantly different ($p=0.108$) between the treatments: it ranged from 89% in the reserve to 99% and 109% in the glyphosate and hexazinone treatments, respectively (Figure 6). The three treatments varied significantly in moss cover ($p=0.024$) and herb layer cover ($p<0.001$). The reserve had the lowest cover of tall shrubs (*Alnus incana* and *Salix* spp.) and the highest cover of low shrub species combined (Figure 6), in contrast to the glyphosate and hexazinone treatments. The percent cover of relatively abundant species in the treatments is summa-

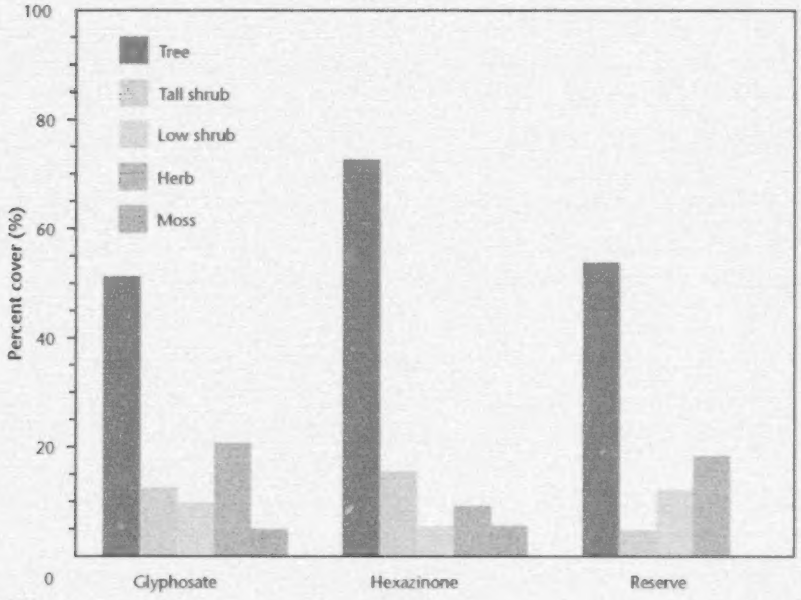

FIGURE 6 *Total cover of plant species by layer in each treatment.*

rized in Table 8. Cover of *Picea glauca* was significantly greater ($p < 0.001$) in the hexazinone treatment, followed by the glyphosate and reserve treatments (Table 8). The reserve had significantly greater cover of *Populus balsamifera* ($p < 0.004$) and *Populus tremuloides* ($p < 0.001$) compared with the other two treatments (Table 8). The cover of *Alnus incana* was significantly ($p = 0.032$) different only between the hexazinone (13.8%) and reserve (less than 1%

TABLE 8 *Mean percent cover of species with significant presence*

Species	Glyphosate	Hexazinone	Reserve	ANOVA *p* value
Alnus incana	4.70ab[1]	13.80a	0.00b	0.032
Calamagrostis canadensis	1.80	0.20	1.60	0.174
Cornus canadensis	1.20	0.80	0.80	0.686
Cornus stolonifera	1.40	1.10	1.20	0.919
Epilobium angustifolium	2.20	0.70	3.10	0.146
Fragaria virginiana	0.90a	0.20b	0.20b	0.003
Lathyrus ochroleucus	0.06a	0.03a	0.28b	<0.001
Lonicera involucrata	0.50	0.50	0.30	0.785
Petasites palmatus	1.00a	0.70a	2.40b	<0.001
Picea glauca	41.10a	64.00b	0.10c	<0.001
Populus balsamifera	2.30a	1.00a	10.90b	0.004
Populus tremuloides	1.00a	5.70a	44.50b	<0.001
Pyrola asarifolia	0.06a	0.01a	0.18b	0.002
Rosa acicularis	2.60a	2.10a	5.80b	0.002
Rubus pubescens	0.40	0.60	0.90	0.676
Salix spp.	7.80	1.70	4.80	0.360
Taraxacum officinale	0.02	0.03	0.02	0.070
Viburnum edule	2.10	1.10	2.70	0.234

1 Means followed by different letters signify statistical difference at $p < 0.05$.

cover) treatments. Although cover of *Salix* species varied from 1.7% in the hexazinone to 7.8% in the glyphosate treatment, the differences were not significant ($p = 0.360$). *Rosa acicularis* was the only low shrub species whose percent cover varied significantly ($p = 0.002$) between the treatments: it was lower in the glyphosate and hexazinone treatments than in the reserve treatment. Cover of common species in the herb layer was less than 3% for each species. *Fragaria virginiana* had greatest cover in the glyphosate treatment, and *Lathyrus ochroleucus*, *Petasites palmatus*, and *Pyrola asarifolia* had greatest cover in the reserve treatment (Table 8).

Invasive non-native species such as *Taraxacum officinale* had a minor presence 30 years after the initial site disturbance that created the treatments (Table 8). The degree of soil disturbance at Stewart Lake was much less than the disturbance created by high-severity site preparation treatments applied at the Inga Lake research site in northeastern British Columbia (Haeussler et al. 2004). The minor presence of non-native species in this study is consistent with the decrease in non-native species at Inga Lake 10–15 years post-disturbance (Haeussler et al. 2004), and in aspen plant communities (Haeussler and Bergeron 2004; Strong 2004).

The variety of substrates and conditions created after forest harvesting tend to result in greater tree species diversity than that following wildfire (Taylor et al. 2013). Although little mineral soil was exposed after winter shearing was conducted on the sites in this study, even a relatively minor proportion (e.g., < 5%) of the area with exposed mineral soil or with thin (< 2 cm) forest floor would provide suitable substrates for seed-borne species, and thus favour increased species diversity (Taylor et al. 2013). In contrast, the removal of woody debris during the initial shearing would have reduced the availability of decomposing wood as a regeneration substrate in the future, which could lead to decreased plant diversity. It is possible that the glyphosate and hexazinone treatment areas had greater plant species diversity due to the shorter time since the initial disturbance for the chemical treatments compared to the wildfire of the reserve treatment, and to the canopy disturbance created by the 1993 broadleaf thinning treatment, which may have promoted and sustained this diversity (Widenfalk and Weslien 2009).

Pyrola asarifolia was one of four mixotrophic species (plants that receive carbon from both photosynthesis and their mycorrhizal fungi) found in the study sites. Disturbances such as site preparation can have negative effects on the presence or abundance of *P. asarifolia* and *Orthilia secunda* up to 10 years post-treatment (Haeussler et al. 1999). While *P. asarifolia* cover varied significantly ($p = 0.002$) between the treatments (Table 8), the combined percent cover of the four mixotrophic species present (*P. asarafolia*, *P. chlorantha*, *Orthilia secunda*, and *Castilleja minuata*) was not significantly different ($p = 0.137$) between the three treatments.

Calamagrostis canadensis cover was 1.8% or less (Table 8), and was not significantly different between the three treatments. *C. canadensis* can dominate plant communities shortly after disturbance but becomes a minor component of the plant community as the tree and tall shrub canopy develops and provides shade (Lieffers and Stadt 1994; Dunbar et al. 2011). One year after treatment, *C. canadensis* dominated all glyphosate plots, in contrast to the hexazinone plots, which had less than 1% *C. canadensis* cover (unpublished file note). On this site, recalcitrant competitive species such as *C. canadensis* did not maintain dominance in the understorey over time, in spite of the relatively intensive chemical treatment management regime (Aubin et al. 2014).

Question: How did the treatments influence future timber yields?
Stand density is expected to decline in all three treatment areas (Figure 7). At age 100, all three treatments, conifer or broadleaf dominated, would have less than 1000 sph in total. Long-lived aspen, which maintain stand integrity well over 100 years, are common in northeastern British Columbia (Kabzems and Garcia 2004). To reflect this in the MGM simulations, the option to accelerate mortality after maximum basal area is achieved was not employed.

Mixedwood Growth Model simulations included only aspen, balsam poplar, and white spruce because the model does not have the ability to incorporate the tall willow and alder that were present on the study sites. Tall willow and alder would rapidly drop out due to shading, particularly in the conifer stand. These tall shrub species were still an influential part of the canopy dynamics at age 28. The legacy of their influence on the relative growth of spruce on the glyphosate and hexazinone treatments would not be captured in many studies of stand dynamics and succession in the literature.

The maximum basal area in the aspen-dominated reserve treatment may have occurred before the 2012 measurement, when the aspen were 41 years of age (Figure 8). In the MGM simulations, the spruce-dominated hexazinone treatment achieved a maximum basal area of nearly 50 m^2/ha at 80 years, while the glyphosate treatment achieved a maximum of 40 m^2/ha for spruce at 80–100 years.

The MGM simulations of stand total volumes (Figure 9) indicated that, by 60 years post-disturbance, both the glyphosate and hexazinone treatments would have more total volume of tree species than the reserve treatment. In the simulations, the aspen and balsam poplar component of the glyphosate and hexazinone treatments declined rapidly between years 40 and 60; there-

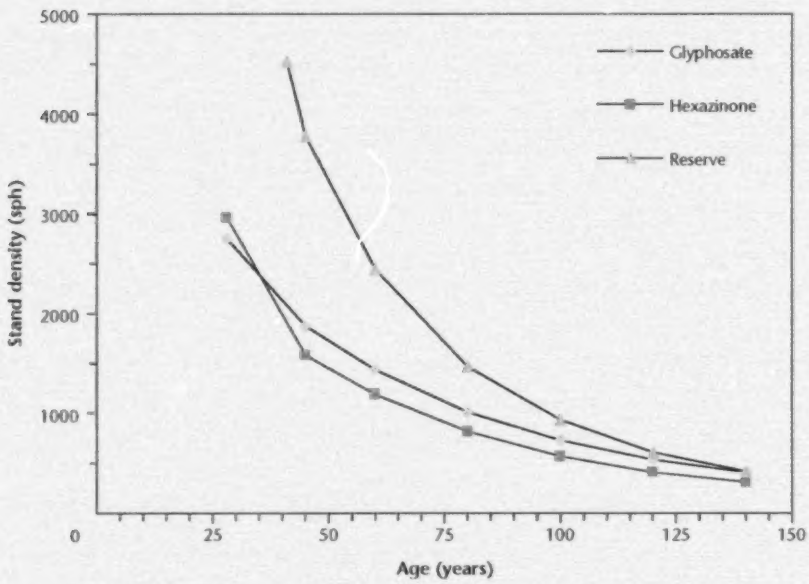

FIGURE 7 *Mixedwood Growth Model projections of stand density (stems per hectare [sph]) by treatment area. The model combines aspen, balsam poplar, and white spruce densities, and simulates future stand mortality.*

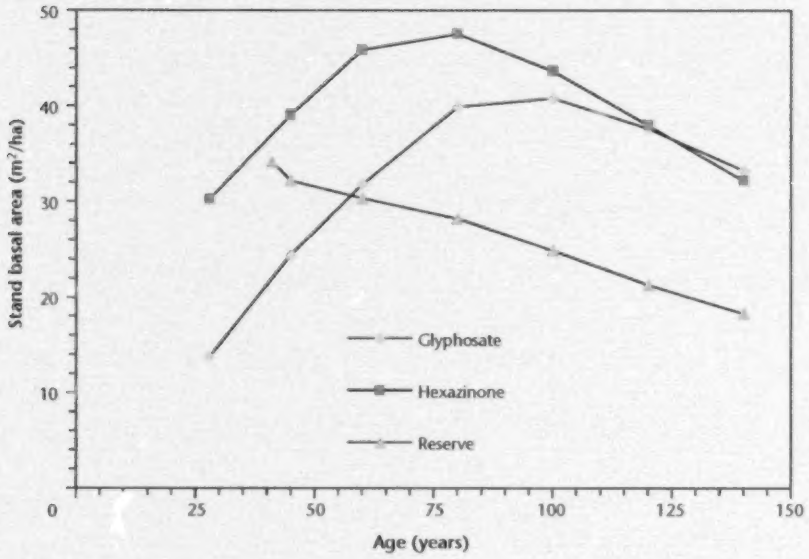

FIGURE 8 *Mixedwood Growth Model projections of stand basal area by treatment area. The model combines aspen, balsam poplar, and white spruce basal areas, and simulates future stand development.*

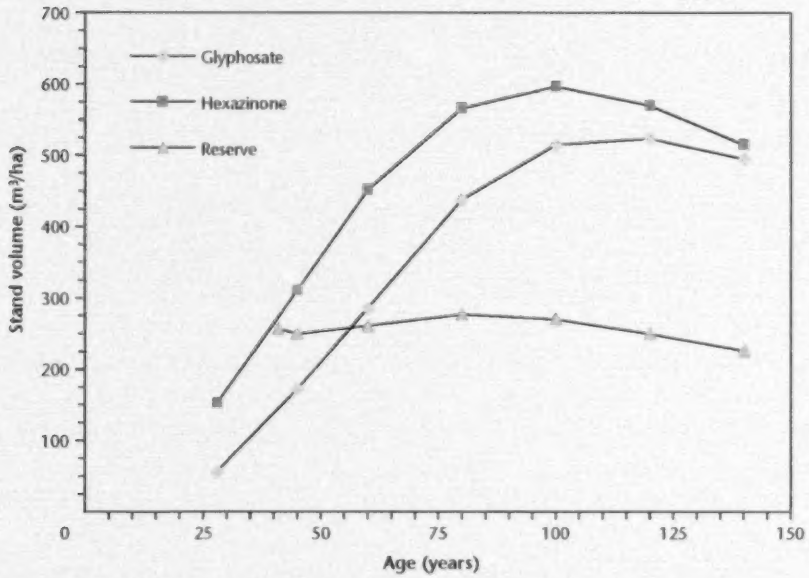

FIGURE 9 *Mixedwood Growth Model projections of total stand volume by treatment area. The model combines aspen, balsam poplar, and white spruce volumes to simulate future stand development.*

fore, the greater total volume would be almost all conifer volume. The MGM projected conifer volumes were at the high end of the spectrum for boreal white spruce. The general trend of longer rotation time favouring volume accumulation by white spruce over aspen is reflected in this simulation.

Twenty-eight years after establishment, the glyphosate and hexazinone treatment areas were mixed-species stands with about 20% stand basal area occupied by aspen or balsam poplar. A stand-level model such as the MGM is not able to portray the short-range variability in tree composition and structure that occurred in these stands, which was quantified as high variability in the summary tables. The reserve treatment was more homogeneous in species composition and structure than the glyphosate and hexazinone treatments. Site history has reduced the probability of natural conifer establishment in the reserve treatment. Logging and short-interval wildfires initially reduced seed source potential. The reserve treatment will lack a viable seed source until the surrounding young white spruce plantations begin to produce large amounts of seed at 40 years of age or older.

4 MANAGEMENT IMPLICATIONS

The Stewart Lake trial was an early attempt at using pre-harvest (pre-disturbance) chemical applications to attain forest management objectives. The original management objective of creating a conifer-dominated stand was not achieved by either the glyphosate or hexazinone applications alone. A subsequent broadleaf thinning in combination with the pre-harvest chemical application did result in good establishment and growth of white spruce as part of a mixed-species stand up to year 28.

White spruce dominated the basal area of the two chemically treated areas, and aspen dominated the reserve treatment. The strength of facilitation and competition interactions and the balance between positive and negative effects will combine to create successional change in these mixedwood stands (St. Clair et al. 2013). The reserve treatment is following the well-documented post-wildfire successional development pattern of boreal aspen ecosystems.

Forty-one years after disturbance, the reserve treatment had only 100 sph of white spruce regeneration, on average. This result documents how the combined effect of seed source removal and short-interval wildfires affect subsequent stand composition and development in boreal mixedwoods. Patterns of boreal tree regeneration the first few years after fire are maintained for several decades of stand development (Johnstone et al. 2004). Thus, post-disturbance recruitment in boreal ecosystems strongly sets the course of future stand development. Particularly where wildfire and reduction of spruce seed sources have resulted in a dramatic shift in tree species composition, planting of white spruce is a viable technique for re-establishing the pre-disturbance forest composition.

Mixedwood Growth Model stand yield projections reflected the expected trends in spruce-dominated mixedwoods compared with aspen types; that is, greater tree volumes in spruce types as time since disturbance increases. The spruce-dominated glyphosate and hexazinone treatments had a mixture of aspen and balsam poplar at year 28, but in the MGM stand-level simulations, the number of broadleaf trees were projected to decrease and not contribute any noticeable amount of volume beyond 60 years of stand development.

Willow and alder were important components of the plant community, and their relative abundance in the treatments at year 28 reflected the initial effectiveness of the hexazinone in controlling willow, and the ability of alder to establish by seed post-treatment. Willow presence in glyphosate treatments and alder presence in hexazinone treatments were also found 12 years post-treatment in a separate experiment located 20 km west of this study site (Harper et al. 1997). Willow and alder comprised a much smaller percentage of stand basal area in the reserve treatment. The aspen and balsam poplar rapidly developed a full canopy, which overtopped the willow and alder, and accelerated the mortality of the tall shrubs.

Twenty-eight years after planting, damaging agents were not an important factor in spruce survival and growth at the study site. Compared to white spruce, the trembling aspen had higher levels of damaging agents and standing dead stems, which reflects the stem exclusion phase of natural succession in aspen stands. Hypoxylon canker was present, but there was relatively low occurrence on aspen. Most balsam poplar stems were healthy. The most common damaging agents on balsam poplar were classified as tree competition, or unknown. Moose damage, often combined with vegetation competition, were the most common damaging agents for willow. The presence of dead alder stems was attributed to drought or vegetation competition; *Cytospora* canker was the third most comment agent.

More understorey plant species were recorded in the chemically treated areas than in the reserve. Only two non-native ruderal species, *Taraxacum officinale* and *Trifolium hybridum*, were present in the chemical treatment areas. The greater understorey plant diversity in the chemically treated areas would have been due to the diversity of available habitats rather than the contribution of non-native ruderal species. At Stewart Lake, the silvicultural treatments that established spruce had increased species diversity, which is consistent with results from other experiments where diversity was not reduced by silviculture treatments and conifer plantings (Haeussler et al. 1999) or after glyphosate site preparation (Boateng et al. 2000). Treatment application and intensity was not uniform in this study, which resulted in some deciduous retention and gap formation, and thus increased plant diversity (Widenfalk and Weslien 2009). The 11-year difference since disturbance between the chemical treatments and the reserve treatment may have contributed to the recorded differences, as the aspen-dominated reserve likely lost plant species that occur shortly after disturbance.

Species richness is a transient property. The plant species diversity at the time of measurement should not be considered as stand-level biodiversity (Hauessler et al. 1999). In particular, the shearing and piling treatments conducted after the chemical application removed standing dead trees, large old trees, and coarse woody debris, which are all key elements for the recruitment of species and maintenance of biological diversity over a longer term than the 30 years post-disturbance documented here.

The combination of treatments applied in this research trial created diverse plant communities, which over time are becoming more similar to those that develop after boreal wildfire. Within the limitations of the experimental design and site history, this study provides guidance regarding the implications of using a pre-harvest herbicide application to influence successional trends and plant community composition.

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APPENDIX 1a Conifer damage agent and condition codes

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CONIFER DAMAGE AGENT AND CONDITION CODES

FIELD CODES	DESCRIPTION	FIELD CODES	DESCRIPTION
A	**ANIMAL DAMAGE**		
AB	BEAR	AP	PORCUPINE
AC	CATTLE	AS	SQUIRREL
AD	DEER	AV	VOLE
AE	ELK	AX	BIRDS
AH	HARE OR RABBIT	AZ	BEAVER
AM	MOOSE		
AO	PIKA		
N	**ABIOTIC INJURIES**		
NAV	Avalanche or snow slide	NK	FUMEKILL
		NL	LIGHTNING
NB	FIRE	NN	ROAD SALT
ND	DROUGHT	NR	REDBELT
NF	FLOODING	NS	SLIDE
NG	FROST	NW	WINDTHROW
NGC	Frost crack	NWS	Windthrow-soil failure
NGH	Frost-heaved	NWT	Windthrow-treatment
NGK	Shoot / bud frost kill or harvest related	NX	WIND SCARRING OR RUBBING
		NY	SNOW, ICE, SNOW PRESS
NH	HAIL	NZ	SUNSCALD
D	**DISEASE**		
DB	BROOM RUST		
DBF	Fir broom rust *Melampsorella caryophyllacearum*		
DBS	Spruce broom rust *Chrysomyxa arctostaphyli*		
DD	STEM DECAYS		
DDA	White mottled rot *Ganoderma applanatum*		
DDD	Sulfur fungus *Laetiporus sulphureus*		
DDE	Rust-red stringy rot *Echinodontium tinctorium*		
DDF	Brown crumbly rot *Fomitopsis pinicola*		
DDO	Brown cubical butt & pocket rot of cedar *Postia sericeomollis*		
DDP	Red ring rot *Phellinus pini*		
DDQ	Brown trunk rot (quinine fungus) *Fomitopsis officinalis*		
DF	FOLIAGE DISEASES		
DFA	Western pine aster rust *Coleosporium asterum*		

FIELD CODES	DESCRIPTION
DFB	Delphinella tip blight *Delphinella* spp.
DFC	Large-spored spruce-labrador tea rust *Chrysomyxa ledicola*
DFD	Spruce needle cast *Lirula macrospora*
DFE	Elytroderma needle and shoot disease *Elytroderma deformans*
DFH	Larch needle blight *Hypodermella laricis*
DFJ	Phaeoseptoria needle cast *Phaeoseptoria contortae*
DFL	Pine needle cast *Lophodermella concolor*
DFM	Larch needle cast *Meria laricis*
DFN	Leptomelanconium needle blight *Leptomelanconium pinicola*
DFO	Lophodermium needle cast *Lophodermium seditiosum*
DFP	Fir-fireweed rust *Pucciniastrum epilobii*
DFR	Douglas-fir needle cast *Rhabdocline pseudotsugae*
DFS	Dothistroma (red band) needle blight *Mycosphaerella pini*
DFU	Cedar leaf blight *Didymascella thujina*
DFW	Swiss needle cast *Phaeocryptopus gaeumannii*
DFX	Brown felt blight *Herpotrichia spp.*
DFY	Hendersonia needle cast *Hendersonia pinicola*
DFZ	Rhizosphaera needle cast *Rhizosphaera kalkhoffii*
DL	LEADER OR BRANCH DIEBACKS
DLD	Dermea canker *Dermea pseudotsugae*
DLF	Red flag disease *Potebniamyces balsamicola*
DLK	Conifer cytospora canker *Leucostoma kunzei*
DLP	Diaporthe canker *Diaporthe lokoyae*
DLS	Sydowia tip dieback *Sclerophoma pithyophila*
DFT	Sirococcus tip blight *Sirococcus strobilinus*
DM	DWARF MISTLETOES
DMF	Douglas-fir dwarf mistletoe *Arceuthobium douglasii*
DMH	Hemlock dwarf mistletoe *Arceuthobium tsugense*
DML	Larch dwarf mistletoe *Arceuthobium laricis*
DMP	Lodgepole pine dwarf mistletoe *Arceuthobium americanum*
DR	ROOT DISEASES
DRA	Armillaria root disease *Armillaria ostoyae*
DRB	Blackstain root disease *Leptographium wageneri*
DRC	Laminated root rot (cedar form) *Phellinus weirii*
DRL	Laminated root rot (Fd form) *Phellinus sulphurascens*
DRN	Annosus root disease *Heterobasidion annosum*
DRR	Rhizina root disease *Rhizina undulata*

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FIELD CODES		DESCRIPTION
	DRS	Schweinitzii butt rot *Phaeolus schweinitzii*
	DRT	Tomentosus root rot *Inonotus tomentosus*
DS		STEM DISEASE (CANKER OR RUST)
	DSA	Atropellis canker *Atropellis piniphila*
	DSB	White pine blister rust *Cronartium ribicola*
	DSC	Comandra blister rust *Cronartium comandrae*
	DFE	Elytroderma needle and shoot disease *Elytroderma deformans*
	DSG	Western gall rust *Endocronartium harknessii*
	DSS	Stalactiform blister rust *Cronartium coleosporioides*
I		**INSECTS**
IA		APHIDS *OR ADELGIDS*
	IAB	Balsam woolly adelgid *Adelges piceae*
	IAC	Giant conifer aphid *Cinara spp*
	IAG	Cooley spruce gall adelgid *Adelges cooleyi*
	IAL	Larch cone woolly aphid *Adelges lariciatus*
	IAS	Spruce aphid *Elatobium abietinum*
IB		BARK BEETLES
	IBB	Western balsam bark beetle *Dryocoetes confusus*
	IBD	Douglas-fir beetle *Dendroctonus pseudotsugae*
	IBE	Silver fir beetle *Pseudohylesinus sericeus*
	IBF	Fir engraver beetle *Scolytus ventralis*
	IBH	Hylurgops beetle *Hylurgops rugipennis*
	IBI	Engraver beetles *Ips*
	IBL	Lodgepole pine beetle *Dendroctonus murryanae*
	IBM	Mountain pine beetle *Dendroctonus ponderosae*
	IBP	Twig beetles *Pityogenes, Pityophthorus spp*
	IBS	Spruce beetle *Dendroctonus rufipennis*
	IBT	Red turpentine beetle *Dendroctonus valens*
	IBW	Western pine beetle *Dendroctonus brevicomis*
ID		DEFOLIATING INSECTS
	IDA	Black army cutworm *Actebia fennica*
	IDB	Two-year budworm *Choristoneura biennis*
	IDC	Larch casebearer *Coleophora laricella*
	IDE	Spruce budworm *Choristoneura fumiferana*
	IDG	Green-striped forest looper *Melanolophia imatata*
	IDH	Western blackheaded budworm *Acleris gloverana*
	IDI	Pine needle sheath miner *Zelleria haimbachi*
	IDL	Western hemlock looper *Lambdina fiscellaria lugubrosa*

FIELD CODES		DESCRIPTION
	IDP	Larch sawfly *Pristiphora erichsonii*
	IDS	Conifer sawflies *Neodiprion spp.*
	IDT	Douglas-fir tussock moth *Orgyia pseudotsugata*
	IDV	Variegated cutworm *Peridroma saucia*
	IDW	Western spruce budworm *Choristoneura occidentalis*
	IDZ	Western false hemlock looper *Nepytia freemeni*
IS		SHOOT AND STEM INSECTS
	ISB	Western cedar borer *Trachykele blondeli*
	ISE	European pine shoot moth *Rhyaconia buoliana*
	ISG	Gouty pitch midge *Cecidomyia piniinopis*
	ISP	Pitch nodule moths *Petrova spp.*
	ISS	Western pine shoot borer *Eucosma sonomana*
	ISQ	Sequoia pitch moth *Synanthedon sequoiae*
IW		WEEVILS
	IWC	Conifer seedling weevil *Steremnius carinatus*
	IWM	Magdalis sp.
	IWP	Lodgepole pine terminal weevil *Pissodes terminalis*
	IWS	White pine weevil (on spruce) *Pissodes strobi*
	IWW	Warren's root collar weevil *Hylobius warreni*
	IWY	Cylindrocopturus weevil *Cylindrocopturus spp*
	IWZ	Yosemite bark weevil *Pissodes schwartzii*
M		**MITE DAMAGE (TRISETACUS SPECIES)**
T		**TREATMENT INJURIES**
TC		CHEMICAL
TH		HARVESTED
TL		LOGGING
TM		OTHER MECHANICAL DAMAGE (NON-LOGGING)
TP		PLANTING
	TPM	Planting — poor microsite
TR		PRUNING
TT		THINNING OR SPACING
V		**VEGETATION PROBLEMS**
VH		HERBACEOUS COMPETITION
VP		VEGETATION PRESS
VS		SHRUB COMPETITION
VT		TREE COMPETITION

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DECIDUOUS DAMAGE AGENT AND CONDITION CODES

FIELD CODES		DESCRIPTION	FIELD CODES		DESCRIPTION
A		**ANIMAL DAMAGE**			
AB		BEAR	AP		PORCUPINE
AC		CATTLE	AS		SQUIRREL
AD		DEER	AV		VOLE
AE		ELK	AX		BIRDS
AH		HARE OR RABBIT	AZ		BEAVER
AM		MOOSE			
AO		PIKA			
N		**ABIOTIC INJURIES**			
	NAV	Avalanche or snow slide	NH		HAIL
			NK		FUMEKILL
NB		FIRE	NL		LIGHTNING
NC			NN		ROAD SALT
	NCA	Aspen decline	NR		REDBELT
	NCB	Birch decline	NS		SLIDE
ND		DROUGHT	NW		WINDTHROW
NF		FLOODING		NWS	Windthrow-soil failure
NG		FROST		NWT	Windthrow-treatment
	NGC	Frost crack	NX		WIND SCARRING OR RUBBING
	NGH	Frost-heaved	NY		SNOW, ICE, SNOW PRESS
	NGK	Shoot / bud frost kill or harvest related	NZ		SUNSCALD
D		**DISEASE**			
DD		STEM DECAYS			
	DDA	White mottled rot *Ganoderma applanatum*			
	DDB	White spongy trunk rot *Formes fomentarius*			
	DDC	Brown cubical rot of birch *Piptoporus betulinus*			
	DDD	Sulfur fungus *Laetiporus sulphureus*			
	DDF	Brown crumbly rot *Fomitopsis pinicola*			
	DDG	Sterile conk trunk rot of birch *Inonotus obliquus*			
	DDH	Hardwood trunk rot *Phellinus igniarius*			
	DDT	Aspen trunk rot *Phellinus tremulae*			
DF		FOLIAGE DISEASES			
	DFF	Marssonina leaf spots and blights *Marssonina spp*			

FIELD CODES		DESCRIPTION
	DFG	Cottonwood leaf rust *Melampsora occidentalis*
	DFI	Linospora leaf blotch *Linospora tetraspora*
	DFK	Septoria leaf spot *Septoria populicola*
	DFQ	Ink spot of aspen *Ciborinia whetzelii*
	DFV	Leaf rust *Melampsora spp.*
DL		LEADER OR BRANCH DIEBACKS
	DLP	Diaporthe canker *Diaporthe lokoyae*
	DLV	Aspen & poplar leaf and shoot blights *Venturia spp.*
DR		ROOT DISEASES
	DRA	Armillaria root disease *Armillaria ostoyae*
DS		STEM DISEASE (CANKER OR RUST)
	DSE	Sooty bark canker *Encoelia pruinosa*
	DSH	Hypoxylon canker *Entoleuca mammatum*
	DSP	Cryptosphaeria canker *Cryptosphaeria populina*
	DSR	Ceratocystis canker *Ceratocystis fimbriata*
	DST	Target canker *Nectria galligena*
	DSY	Cytospora canker *Valse sordida*
I		**INSECTS**
ID		DEFOLIATING INSECTS
	IDA	Black army cutworm *Actebia fennica*
	IDD	Western winter moth *Erannis vancouverensis*
	IDF	Forest tent caterpillar *Malacosoma disstria*
	IDJ	Gray forest looper *Caripeta divista*
	IDK	Northern tent caterpillar *Malacosoma californicum*
	IDM	Gypsy moth *Lymantria dispar*
	IDN	Birch leaf miners *Fenusa pusilla and Profenusa thomsoni*
	IDO	Filament bearer *Nematocampa filamentaria*
	IDR	Alder sawfly *Eriocampa ovata*
	IDU	Satin moth *Leucoma salicis*
	IDV	Variegated cutworm *Peridroma saucia*
	IDX	Large aspen tortrix *Choristoneura conflictana*
	IDY	Birch-aspen leafroller *Epinotia solandriana*
	ID1	Leaf beetles *Chrysomela spp.*
	ID2	Bruce spanworm *Operophtera bruceata*

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FIELD CODES		DESCRIPTION
	ID3	Winter moth *Operophtera brumata*
	ID4	Cottonwood sawfly *Nematus currani*
	ID5	Fall webworm *Hyphantria cunea*
	ID6	Aspen leaf miner *Phyllocristis populiella*
	ID7	Woolly alder sawfly *Eriocampa ovata*
	ID8	Aspen leaf roller *Pseudexentera oregonana*
	ID9	Birch leaf skeletonizer *Buccaletrix spp.*
	IEA	Unidentified aspen defoliation
	IEF	Cottonwood leaf skeletonizer *Phyllonorycytes apparella*
	IEJ	Willow leafminer *Micrurapteryx salicifoliella*
IS		SHOOT INSECTS
	ISA	Bronze birch borer *Agrilus anxius*
	ISC	Poplar borer *Saperda calcarata*
	ISW	Poplar and willow borer *Cryptorhynchus lapathi*
T		**TREATMENT INJURIES**
TC		CHEMICAL
TH		HARVESTED
TL		LOGGING
TM		OTHER MECHANICAL DAMAGE (NON-LOGGING)
TP		PLANTING
	TPM	Planting — poor microsite
TR		PRUNING
TT		THINNING OR SPACING
V		**VEGETATION PROBLEMS**
VH		HERBACEOUS COMPETITION
VP		VEGETATION PRESS
VS		SHRUB COMPETITION
VT		TREE COMPETITION

APPENDIX 2 Plant species list

Scientific name	English name
Trees and shrubs	
Alnus incana	River alder
Alnus viridis	Green alder
Amelanchier alnifolia	Saskatoon
Betula papyrifera	Paper birch
Cornus stolonifera	Red-osier dogwood
Lonicera involucrata	Black twinberry
Picea glauca	White spruce
Pinus contorta	Lodgepole pine
Populus balsamifera	Balsam poplar
Populus tremuloides	Trembling aspen
Ribes lacustre	Black gooseberry
Ribes oxycanthoides	Northern gooseberry
Ribes triste	Red swamp currant
Rosa acicularis	Prickly rose
Rubus idaeus	Red raspberry
Salix spp.	Willows
Shepherdia canadensis	Soopolallie
Spirea betulifolia	Birch-leaved spirea
Symphoricarpos albus	Snowberry
Viburnum edule	Highbush-cranberry
Herbs	
Achillea millefolium	Yarrow
Actaea rubra	Baneberry
Aralia nudicalulis	Wild sarsaparilla
Arctostaphylos uva-ursi	Bearberry
Arnica cordifolia	Heart-leaved arnica
Aster ciliolatus	Fringed aster
Aster conspicuus	Showy aster
Botrychium virginianum	Grape fern
Bromus vulgaris	Columbia brome
Calamagrostis canadensis	Bluejoint
Carex spp.	Sedges
Castilleja miniata	Scarlet paintbrush
Clematis occidentalis	Columbia bower
Cornus canadensis	Bunchberry
Delphinium glaucum	Tall larskpur
Diphasiastrum complanatum	Ground cedar
Epilobium angustifolium	Fireweed
Equisetum arvense	Common horsetail
Equisetum pratense	Meadow horsetail
Equisetum scirpoides	Dwarf scouring-rush
Equisetum sylvaticum	Wood horsetail
Festuca occidentalis	Western fescue
Fragaria virginianum	Wild strawberry
Galium boreale	Northern bedstraw
Galium triflorum	Sweet-scented bedstraw
Geum macrophyllum	Large-leaved avens
Heracleum sphondylium	Cow parsnip
Hieracium sp.	Hawkweed
Lathyrus ochroleucus	Creamy peavine
Leymus innovatus	Rye grass
Linnaeus borealis	Twinflower
Maianthemum canadense	Wild lily-of-the-valley
Maianthemum racemosa	False Solomon's seal

Maianthemum stellata	Star-flowered false Solomon's-seal
Mertensia paniculata	Tall lungwort
Mitella nuda	Mitrewort
Orthilia secunda	One-sided wintergreen
Osmorhiza depauperata	Spreading sweet cicely
Petasites palmatus	Palmate coltsfoot
Platanthera sp.	Orchid
Prosartes trachycarpatra	Rough-fruited fairybells
Pyrola asarifolia	Pink wintergreen
Pyrola chlorantha	Greenish flowered wintergreen
Rubus pubescens	Trailing raspberry
Senecio pauperculus	Balsam groundsel
Solidago canadensis	Canada goldenrod
Stellaria calycantha	Northern starwort
Taraxacum officinale	Dandelion
Thalictrum occidentale	Western meadow rue
Trifolium hybridum	Alsike clover
Trisetum spicatum	Spike trisetum
Vaccinium caespitosum	Dwarf bilberry
Vicia americana	American vetch
Viola canadensis	Canada violet

Mosses and lichens

Brachythecium salebrosum	Golden ragged-moss
Dicranum polysetum	Wavy-leaved moss
Hylocomium splendens	Step moss
Peltigera spp.	Leaf lichens
Pleurozium schreberi	Red-stemmed feathermoss
Ptilium crista-castrensis	Knight's plume